Mass movement susceptibility mapping using satellite optical imagery compared with InSAR monitoring: Zigui County, Three Gorges region, China.

Cem Kincal[(1)], Andrew Singleton[(1)], Peng Liu[(1)], Zhenhong Li[(1)], Jane Drummond[(1)], Trevor Hoey[(1)]
Jan-Peter Muller[(2)], Wei Qu[(1)(3)], Qiming Zeng[(4)], Jingfa Zhang[(5)] and Peijun Du[(6)]
[(1)] School of Geographical and Earth Sciences, University of Glasgow, Glasgow, G12 8QQ, UK
[(2)] Mullard Space Science Laboratory, Department of Space and Climate Physics, University College London, UK
[(3)] College of Geology Engineering and Geomatics, Chang'an Uiversity, Xi'an 710054, China
[(4)] Institute of RS and GIS, Peking University, Beijing 100871, PR China
[(5)] Institute of Crustal Dynamics, China Earthquake Administration, Beijing 100085, China
[(6)]Department of Remote Sensing and Geographic Information Science, China University of Mining and Technology, Xuzhou 221008, China
e-mail: ckincal@ges.gla.ac.uk, zhenhong.li@glasgow.ac.uk

ABSTRACT

Mass movements on steep slopes are a major hazard to communities and infrastructure in the Three Gorges region, China. Developing susceptibility maps of mass movements is therefore very important in both current and future land use planning. This study employed satellite optical imagery and an ASTER GDEM (15 m) to derive various parameters (namely geology; slope gradient; proximity to drainage networks and proximity to lineaments) in order to create a GIS-based map of mass movement susceptibility. This map was then evaluated using highly accurate deformation signals processed using the Persistent Scatterer (PS) InSAR technique. Areas of high susceptibility correspond well to points of high subsidence, which provides a strong support of our susceptibility map.

Keywords: Mass movement; Susceptibility; ASTER imagery; InSAR; Three Gorges

1. INTRODUCTION

The Three Gorges Project (TGP), located on the River Yangtze in Hubei Province, China, has attracted significant scientific attention. In addition to the substantial benefits of TGP (primarily downstream flood protection, hydropower generation and improved navigation), the simultaneous adverse environmental impacts require substantial consideration [1], [2].

Defined as the downward and outward movement of slope-forming material under the influence of gravity [3], this paper uses the term mass movement to include rock falls, topples and flows as well as landslides. The most widespread geohazard associated with TGP is slope instability [4], which frequently affects the built environment and local populations. The development of a susceptibility map is therefore very useful in land use planning and determining any appropriate mitigation measures.

This study aims to prepare a GIS-based susceptibility map of mass movements in Zigui County, China, using parameters for lithology, slope gradient, lineaments and drainage network using a GIS model. The map will then be compared to precise deformation signals measured using the Persistent Scatter Interferometric Synthetic Aperture Radar technique (PS-InSAR).

2. STUDY AREA

The Three Gorges are thought to have been formed by river downcutting of massive limestone mountains of Palaeozoic and Mesozoic age along narrow fault zones [5]. Zigui was located to the west of Xiling Gorge and has been considered an area with a high risk of landsliding due to a 'soft' lithology, high dissection density and steep slopes [6]. However, it is important to note this study refers to the new Zigui County after the old Zigui County (located approximately 45 km upstream from the TGP) was submerged by the TGP reservoir (Fig. 1a).

2.1 Geological Setting

The regional geology of the Three Gorges is double layered consisting of pre-Sinian crystalline basement and a Sinian-Jurassic sedimentary cover comprised of interbedded carbonates, sandstones and shales [7]. Zigui is located on the only outcrop of pre-Sinian metamorphic and magmatic rock in the Huangling anticline which forms a major NNE – SSW orientated structure approximately 50 km in length [6]. Composed of Precambrian granite, dioritic schist and black mica gneiss [8], the strength and stability of the pre-Sinian complex principally explains the location of the TGP.

Geological boundaries (Lithology) can be delineated for the area of interest bordering the Yangtze River (Fig. 1b) using Landsat TM 7-3-1, 7-4-1 and ETM+ 7-3-1 and 7-4-2 band combinations [9].

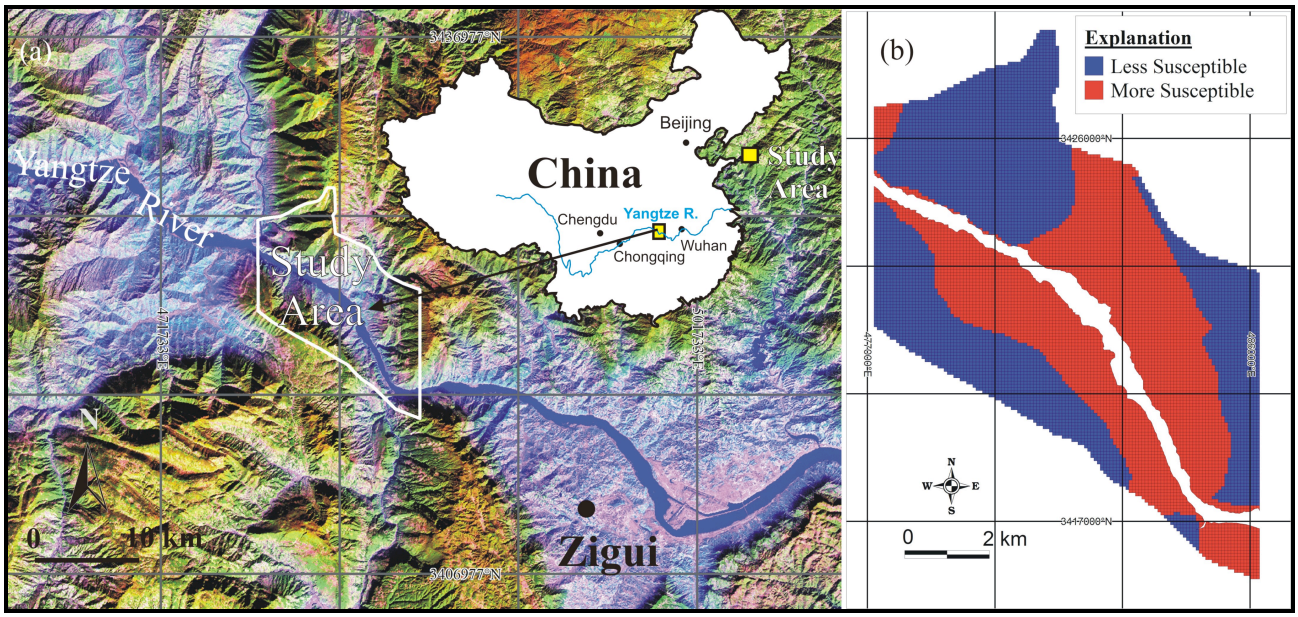

Figure 1. (a) Location map of the study area. The white closed loop represents the area of interest of this paper. (b) Map showing lithological units susceptible to mass movements.

2.2 Characteristics of Mass Movement

A previous study [4] found the classification of slope failure to be strongly influenced by the underlying lithology. In this study, we expect rock falls predominantly on steep limestone slopes. In contrast, block slides along near-planar slip surfaces are expected to dominate steep slopes of sandstone and shale interbeddings.

3. METHODS AND TECHNIQUES

3.1 Susceptibility Mapping

This study has been carried out using remotely sensed Landsat ETM+ and Advanced Spaceborne Thermal Emission Radiometer (ASTER) images, interferometric processing, slope stability analysis and validation. The GIS-model was built using information extracted from ASTER and Landsat ETM+ images (Table 1), ASTER G-DEM data and published literature.

Table 1: Attributes of Landsat and ASTER images used in this study [10]

Acquisition Date	Dataset	Cloud ratio (%)	Path/Row
2006-09-12	Landsat ETM+	0	125/39
2000-07-17	ASTER	3	125/39
2002-09-25	ASTER	5	125/39

A geological map of the study area was prepared using Landsat TM/ETM+ and the two ASTER images. After creating RGB images saved in geotiff format by ENVI software, lithological boundaries were visually identified and delineated using the MapInfo Professional software. The geological categories were then classified into more and less susceptible rock units by rock resistance (Fig. 1b). ASTER G-DEM data with a spatial resolution of 15 m were used to create maps of slope gradient (Fig. 2), drainage network and lineaments [11].

Table 2: Points assigned to each pixel depending on susceptibility factor

Slope Angle		Lithology	
Category	**Point**	**Category**	**Point**
0-10°	10	Less Susceptible	10
11-30°	30	More susceptible	30
> 30°	40		
Lineaments – including Yangtze River		**Drainage – excluding Yangtze River**	
Category	**Point**	**Category**	**Point**
In 25m buffer	10	In 50m river buffer	10
In 25-50m buffer	15	Outside 50m river buffer	0
In 500m Yangtze buffer	30		

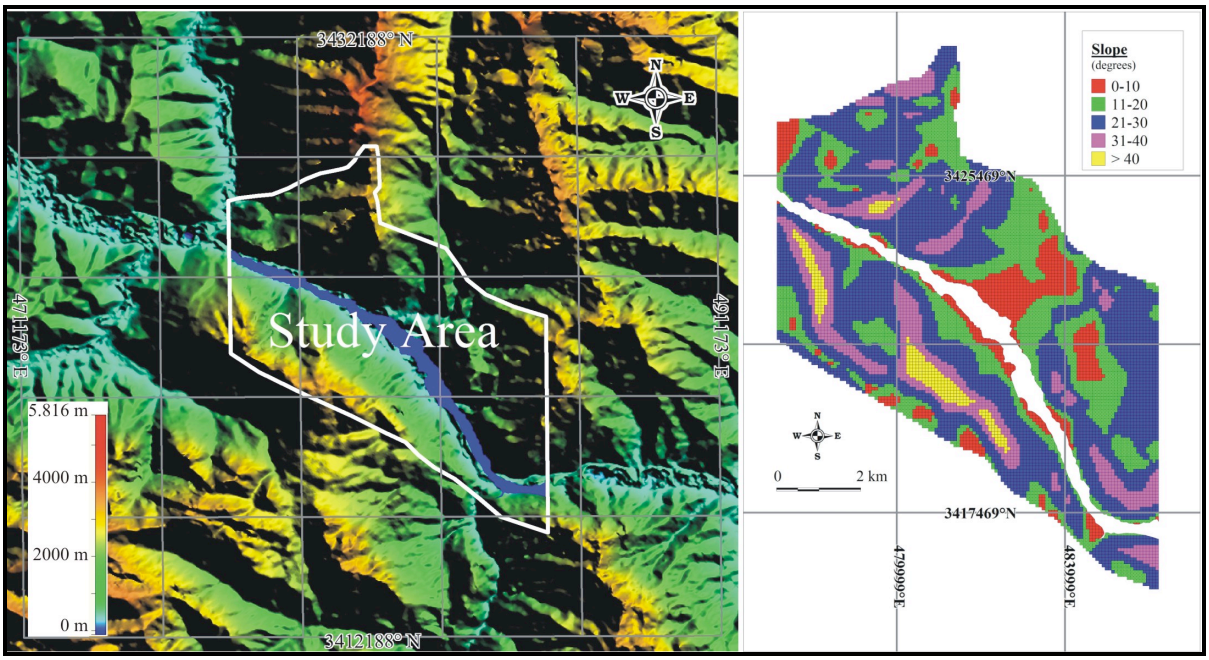

Figure 2. ASTER GDEM and slope map of the study area.

The ability to overlay maps is a key function of any GIS. Having assigned points for each susceptibility factor, as defined in Table 2, a map composed of 'vector pixels' (i.e. sampling grid cells) was created with the associated attribute table having columns for each susceptibility factor. The final susceptibility value for each vector pixel is obtained from the summation of the points for each susceptibility factor.

3.2 PS InSAR

Interferometric SAR (InSAR) can be used to map surface displacements in the Earth's surface from space by calculating the phase differences in complex (magnitude and phase) Synthetic Aperture Radar (SAR) images acquired in similar geometric conditions, but at two different epochs [12]. However, sources of error for the conventional InSAR technique principally arise from variations in atmospheric water content and temporal decorrelation [13]. Persistent Scatterer (PS) InSAR allows reliable deformation measurements to be obtained by identifying single coherent pixels from a long temporal series of interferograms and estimating atmospheric signals [14]. The StaMPS (Stanford Method for Persistent Scatterers) package has proven its ability to study volcano dynamics even in a dense vegetated environment [15]. In this study, the StaMPS package was used to process 13 ENVISAT images from descending track 075 collected between November 2003 and March 2008. The PS-derived mean velocity map is used for further analysis in this paper.

4. SUSCEPTIBILITY ANALYSIS OF MASS MOVEMENTS

The susceptibility of each pixel to mass movements is displayed in Fig. 3 with unit-less values ranging from 20 to 125. Areas of greatest susceptibility are categorised by steep slope gradients, a 'soft' shale/sandstone lithology and in close proximity to the Yangtze River. Smaller features with high susceptibility values observed in the map generally correspond to lineaments and drainage channels. Fig. 3(a) suggests mass movements are more likely to be characterised by block slides with a high connectivity to the stream network. To evaluate the GIS-model, PS-InSAR derived deformation signals were overlaid onto the susceptibility map. In Fig. 3(b), yellow points represent stable pixels, purple points indicate subsidence pixels and blue points imply uplift pixels. It should be noted that the density of PS-InSAR points does not indicate the magnitude of deformation; substantial clusters of PS-InSAR points merely correspond to more populated areas (e.g. towns indicated in black in Fig 3(b), such as Xiangxizhen and Quyuanzhen) which possibly exhibit high radar backscatters from man-made buildings. A simple spatial analysis reveals that 11.87 % of PS Points are located on top of buildings.

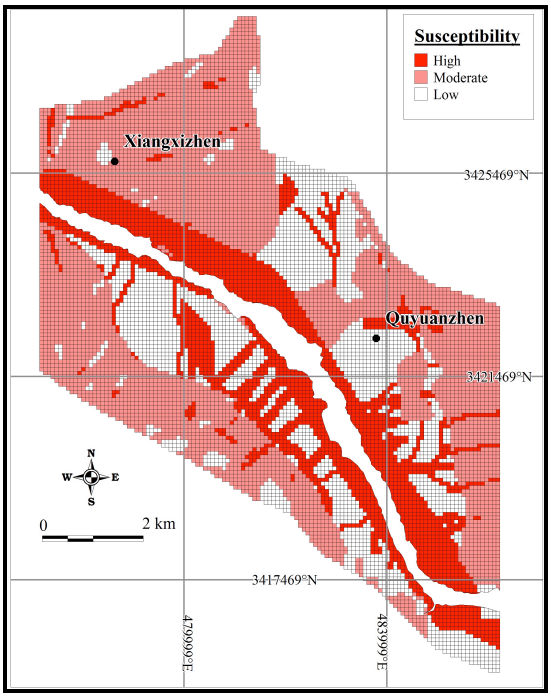

Figure 3(a). Mass movement susceptibility map.

Although PS points are limited to points with good coherence from a long series of interferograms, there is a good correspondence of points to the GIS-based susceptibility model. It is clear in Table 3 that 52.13% of deformation points (subsidence) are located in areas classified by the GIS-model as moderately and highly susceptible to mass movements. We also believe that it is not appropriate to consider each PS-InSAR point in Fig. 3(b) to be a mass movement.

Table 3: Percentages of PS-points versus mass movements susceptibility classes.

Susceptibility / Deformation(mm/yr)	High	Moderate	Low
2 to 8 (uplift)	0.64%	0.94%	0.00%
-2 to 2 (stable)	11.16%	34.19%	0.12%
-8 to -2 (subsidence)	13.21%	38.92%	0.82%

5. CONCLUSIONS

In this study, a mass movement susceptibility map was generated for Zigui County, China, using satellite optical images (specifically ASTER and Landsat) and ASTER GDEM, which agrees well with our PS InSAR derived deformation maps. Our study suggests that, in the study area, 27,5% of the study area is highly susceptible to mass movements, and 71% is at a moderate risk (Fig 3).

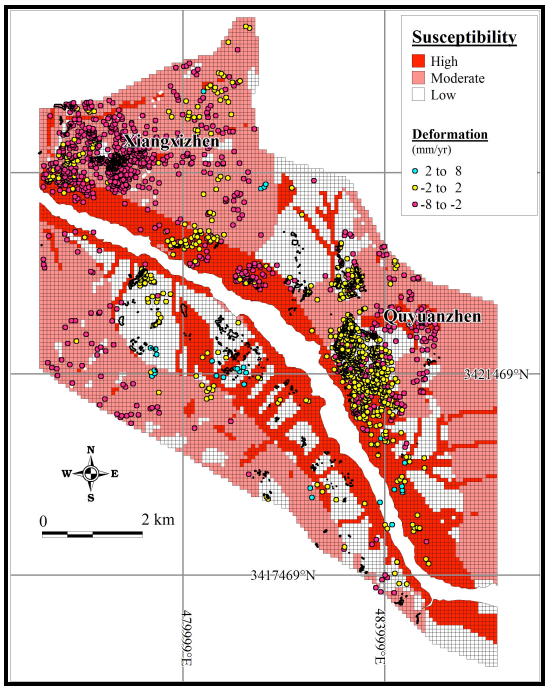

Figure 3(b). Susceptibility map overlaid with PS InSAR derived deformation signals. Note: Black implies areas with buildings, e.g. towns and small villages.

Acknowledgments. This work is supported by The Scientific and Technological Research Council of Turkey fellowship to CK, an EPSRC Industrial Studentship to AS, and a CSC scholarship to PL. Part of this work is also supported by the Natural Environmental Research Council (NERC) through the GAS project (Ref: NE/H001085/1) as well as by a China 863 Project (ID: 2009AA12Z317). The ENVISAT images were supplied through the ESA-MOST Dragon 2 Cooperation Program (ID: 5343).

References

1. Du, Z., 1999. Soil and water conservation and improving ecological environment in the Three Gorges reservoir area. *Resources and Environment in the Yangtze Basin 8(3): 299 – 304.*
2. Tullos, D., 2009. Assessing the influence of environmental impact assessments on science and policy: an analysis of the Three Gorges Project. Journal of Environmental Management 90(Supplement 3): S208 – S223.
3. Dikau, R., 2004. "Mass Movements". In, Goudie, A. (ed.) Encyclopedia of Geomorphology (Vol. 2). London: Routledge. p644 – 653.
4. Fourniadis, I.G., Liu, J.G., and Mason, P.J., 2007. Landslide hazard assessment in the Three Gorges area, China, using ASTER imagery: Wushan – Badong. Geomorphology 84(1-2): 126 – 144.

5. Li, J., Xie, S., and Kuang, M., 2001. Geomorphic evolution of the Yangtze Gorges and the time of their formation. Geomorphology 41(2-3): 125 – 135.
6. Liu, J.G., Mason, P.J., Clerici, N., Chen, S., Davis, A., Miao, F., Deng, H., and Liang, L., 2004. Landslide hazard assessment in the Three Gorges area of the Yangtze river using ASTER imagery: Zigui – Badong. Geomorphology 61(1-2): 171 – 187.
7. Wu, S., Shi, L., Wang, R., Tan, C., Hu, D., Mei, Y., and Xu, R., 2001. Zonation of the landslide hazards in the forereservoi region of the Three Gorges Project on the Yangtze River. Engineering Geology 59(1-2): 51 – 58.
8. Fourniadis, I.G., and Liu, J.G., 2007. Landslides in the Wushan-Zigui region of the Three Gorges, China. Quarterly Journal of Engineering Geology and Hydrogeology 40(2): 115 – 122.
9. Kincal, C., Under Review. Landslide susceptibility mapping integrating GIS and InSAR techniques: Three Gorges, Yangtze River (China).
10. Maryland, U.o. Global Land Cover Facility Earth Science Data Interface [online]. Available from: http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp. [Accessed 01/03/2010];
11. MapInfo Professional Software Manual, 2010. http://reference.mapinfo.com/software/mapinfo_pro/english/9.0/MI_UG.pdf
12. Massonnet, D., and K. L. Feigl (1998), Radar interferometry and its application to changes in the Earth's surface, Rev. Geophys., 36(4), 441-500.
13. Hanssen, R.F., 2001. Radar interferometry: data interpretation and error analysis. Dordrecht: Kluwer Academic Publishers.
14. Ferretti, A., Prati, C., and Rocca, F., 2001. Permanent scatterers in SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing 39(1): 8 – 20.
15. Hooper, A., P. Segall, and H. Zebker (2007), Persistent scatterer interferometric synthetic aperture radar for crustal deformation analysis, with application to Volcán Alcedo, Galápagos, Journal of Geophysical Research, 112, B07407, doi:07410.01029/02006JB004763.